This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: B311 – 22

Standard Test Method for Density of Powder Metallurgy (PM) Materials Containing Less Than Two Percent Porosity[1]

This standard is issued under the fixed designation B311; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the U.S. Department of Defense.

1. Scope*

1.1 This test method covers the determination of density for powder metallurgy (PM) materials containing less than two percent porosity and for cemented carbides. This test method is based on the water displacement method.

NOTE 1—A test specimen that gains mass when immersed in water indicates the specimen contains surface-connected porosity. Unsealed surface porosity will absorb water and result in calculated density values higher than the true value. This test method is not applicable if this problem occurs, and Test Methods B962 should be used instead.

1.2 *Units*—With the exception of the values for density and the mass used to determine density, for which the use of the gram per cubic centimetre (g/cm^3) and gram (g) units is the long-standing industry practice, the values in SI units are to be regarded as standard. The values given in parentheses after SI units are provided for information only and are not considered standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

B243 Terminology of Powder Metallurgy

B962 Test Methods for Density of Compacted or Sintered Powder Metallurgy (PM) Products Using Archimedes' Principle

E456 Terminology Relating to Quality and Statistics

E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method

3. Terminology

3.1 Definitions of powder metallurgy (PM) terms can be found in Terminology B243. Additional descriptive material is available under "General Information on PM" on the ASTM B09 web page.

4. Summary of Test Method

4.1 Using an analytical balance, the test specimen is first weighed in air and then in water. The density is determined by calculation using Archimedes' principle.

5. Significance and Use

5.1 For PM materials containing less than two percent porosity, a density measurement may be used to determine if the part has been densified, either overall or in a critical region, to the degree required for the intended application. Density alone cannot be used for evaluating the degree of densification because chemical composition and heat treatment affect the pore-free density.

5.2 For cemented carbides, a density measurement is normally used to determine if there is any significant deviation in composition of the carbide grade. For straight tungsten carbide-cobalt grades, the relationship is straightforward. For complex carbide grades (for example, grades containing tantalum carbide or titanium carbide, or both, in addition to tungsten carbide-cobalt), the situation is more complicated. If the measured density is beyond the specified limits, the composition is outside of the specified limits. A measured density within the specified limits does not ensure correct composition; compensation between two or more constituents could result in the expected density with the wrong composition. Density alone cannot be used for evaluating a cemented carbide grade.

[1] This test method is under the jurisdiction of ASTM Committee B09 on Metal Powders and Metal Powder Products and is the direct responsibility of Subcommittee B09.11 on Near Full Density Powder Metallurgy Materials.

Current edition approved Sept. 1, 2022. Published September 2022. Originally approved in 1956. Last previous edition approved in 2017 as B311 – 17. DOI: 10.1520/B0311-22.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

Copyright © ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959. United States

6. Apparatus

6.1 *Analytical Balance*—Precision single-pan analytical balance that will permit readings within 0.01% of the test specimen mass. See Table 1. The analytical balance shall be supported in a manner to eliminate mechanical vibrations and be shielded from air drafts.

6.2 *Water*—Distilled or deionized and preferably degassed water to which 0.05 to 0.1 volume percent of a wetting agent has been added to reduce the effects of surface tension. The density of distilled water changes as a function of water temperature and therefore should be accounted for when calculating the density of the specimen; see Table 2.

NOTE 2—Degassing the water by evacuation, boiling, or ultrasonic agitation helps to prevent air bubbles from collecting on the test specimen and specimen support when immersed in water.

6.3 *Water Container*—A glass beaker or other suitable transparent container should be used to contain the water.

NOTE 3—A transparent container makes it easier to see air bubbles adhering to the test specimen and specimen support when immersed in water.

NOTE 4—For the most precise density determination, the water container should be of a size that the level of the water does not rise more than 2.5 mm (0.10 in.) when the test specimen is lowered into the water.

6.4 *Test Specimen Support for Weighing in Water*—Two typical arrangements are shown in Fig. 1. The suspension wire may be twisted around the test specimen, or the test specimen may be supported in a wire basket that is attached to the suspension wire. For either arrangement, a single corrosion resistant wire—for example, austenitic stainless steel, copper, nichrome—shall be used for the basket and suspension wire. For the maximum recommended diameter of suspension wire to be used for various mass ranges, see Table 3.

NOTE 5—For the most precise density determinations, it is important that the mass and volume of all supporting wires immersed in water be minimized.

6.5 *Thermometer*—A thermometer to measure the temperature of the water to the nearest 0.5 °C (1 °F).

7. Preparation of Test Specimens

7.1 A complete part or a section of a part may be used for the test specimen. For the highest precision, the test specimen shall have a minimum mass of 5.0 g. If less precision can be tolerated, several test specimens may be used to reach the minimum mass, provided each test specimen has a mass of not less than 1.0 g.

NOTE 6—For metal injection molded (MIM) parts of less than 1.0 g, several parts may be used to reach the minimum mass.

7.2 Thoroughly clean all surfaces of the test specimen to remove any adhering foreign materials such as dirt or oxide scale. Take care with cut specimens to avoid rough surfaces to which an air bubble may adhere. A 100-grit sanding or abrasive grinding is recommended to remove all rough surfaces.

TABLE 1 Balance Readability

Mass, g	Balance Readable to, g
less than 10	0.0001
10 to less than 100	0.001
100 to less than 1000	0.01
1000 to less than 10 000	0.1

TABLE 2 Density of Air-Free Water[A]

Temperature °C	ρ_w g/cm^3	Temperature °F	ρ_w g/cm^3*
15.0	0.9991	60	0.9990
15.5	0.9990	61	0.9989
16.0	0.9989	62	0.9988
16.5	0.9988	63	0.9987
17.0	0.9988	64	0.9986
17.5	0.9987	65	0.9985
18.0	0.9986	66	0.9984
18.5	0.9985	67	0.9983
19.0	0.9984	68	0.9982
19.5	0.9983	69	0.9981
20.0	0.9982	70	0.9980
20.5	0.9981	71	0.9978
21.0	0.9980	72	0.9977
21.5	0.9979	73	0.9975
22.0	0.9978	74	0.9974
22.5	0.9976	75	0.9973
23.0	0.9975	76	0.9972
23.5	0.9974	77	0.9970
24.0	0.9973	78	0.9969
24.5	0.9972	79	0.9967
25.0	0.9970	80	0.9966
25.5	0.9969	81	0.9964
26.0	0.9968	82	0.9963
26.5	0.9966	83	0.9961
27.0	0.9965	84	0.9959
27.5	0.9964	85	0.9958
28.0	0.9962	86	0.9956
28.5	0.9961		
29.0	0.9959	*Interpolated from °C Data	
29.5	0.9958		
30.0	0.9956		

[A] *Metrological Handbook 145*, "Quality Assurance for Measurements," National Institute of Standards and Technology, 1990, p. 9.10.

8. Procedure

8.1 The part or test specimen, the analytical balance and surrounding air shall be at a uniform temperature when weighing is performed.

8.2 For the most precise density determinations, duplicate weighings should be made for all mass measurements. Adjust the analytical balance to zero prior to each weighing. Average the mass determinations before calculating the density.

8.3 For improved repeatability and reproducibility, verify the analytical balance periodically with a standard mass that is approximately equal to the part or test specimen mass.

8.4 Weigh the test specimen in air using an analytical balance. This is mass A. This and all subsequent weighings shall be to the precision stated in Table 1.

8.5 Support the container of water over the pan of the balance using a suitable bridge as shown in Fig. 2. The container of water may also be supported below the balance for weighing larger specimens if the balance has a lower beam hook for this purpose. See Fig. 2b. If this arrangement is used, it is important to shield the suspension wire between the container of water and the bottom of the balance from air drafts.

8.6 Suspend the test specimen support with the test specimen from the beam hook of the balance. The water should

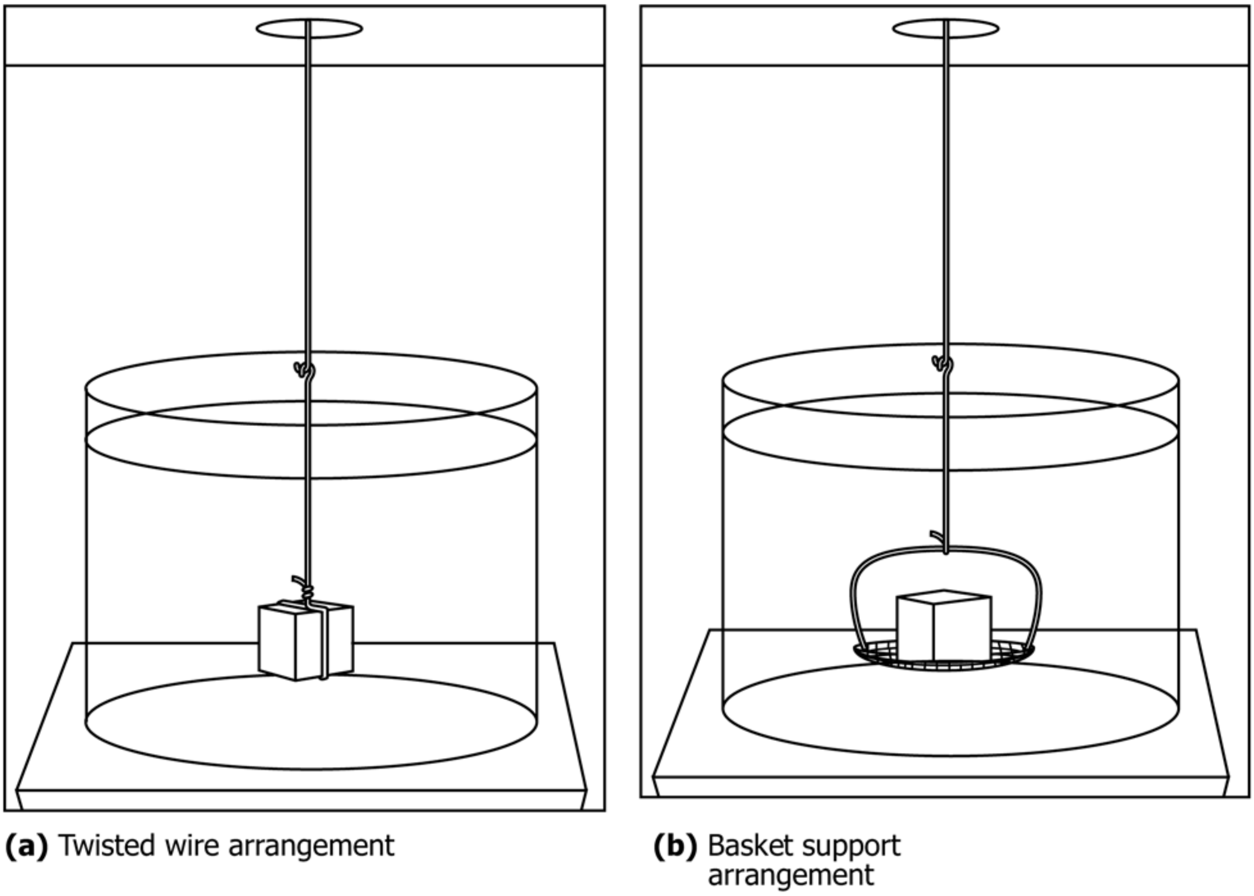

FIG. 1 Methods for Holding the Test Specimen When Weighing in Water

TABLE 3 Maximum Recommended Wire Diameter

Mass, g	Wire Diameter, mm	
	mm	(in.)
less than 50	0.12	(0.005)
50 to less than 200	0.25	(0.010)
200 to less than 600	0.40	(0.015)
600 and greater	0.50	(0.020)

cover any wire twists and the specimen support basket by at least 6 mm (¼ in.) to minimize the effect of surface tension forces on the weighing. Care should be taken to ensure that the test specimen and specimen support hang freely from the balance beam hook, are free of air bubbles where immersed in the water, and are at the same temperature as the water and balance. Care should also be taken to ensure the surface of the water is free of dust particles.

8.7 Weigh the test specimen and specimen support immersed in water. This is mass B. The formation of bubbles on the surface of the specimen may indicate that the surface is permeable. If the mass of the specimen increases by more than 0.01 % of mass A during weighing in water, Test Methods B962 should be used for density determination.

8.8 Remove the test specimen. Weigh the test specimen support immersed in water at the same depth as before. This is mass C. Care should be taken to ensure that the suspension support is free of air bubbles and that the suspension wire is not immersed below its normal hanging depth as a change in depth will change the measured mass.

NOTE 7—Some balances are capable of being tared. This automatically removes the necessity of reweighing the specimen support every time. In this case, tare the specimen support alone, immersed in water to the same depth as with the specimen, before weighing the specimen support and specimen immersed in water. The mass of the specimen support and specimen immersed in water is mass F, which replaces mass B minus mass C.

8.9 Measure the temperature of the water to the nearest 0.5 °C (1 °F) and record its density ρ_w, at that temperature, from Table 2.

9. Calculation

9.1 Calculate the density as follows:

$$\text{Density} = D = \text{Mass/Volume} \quad (1)$$

$$D = A/\frac{[A-(B-C)]}{\rho_w} \quad (2)$$

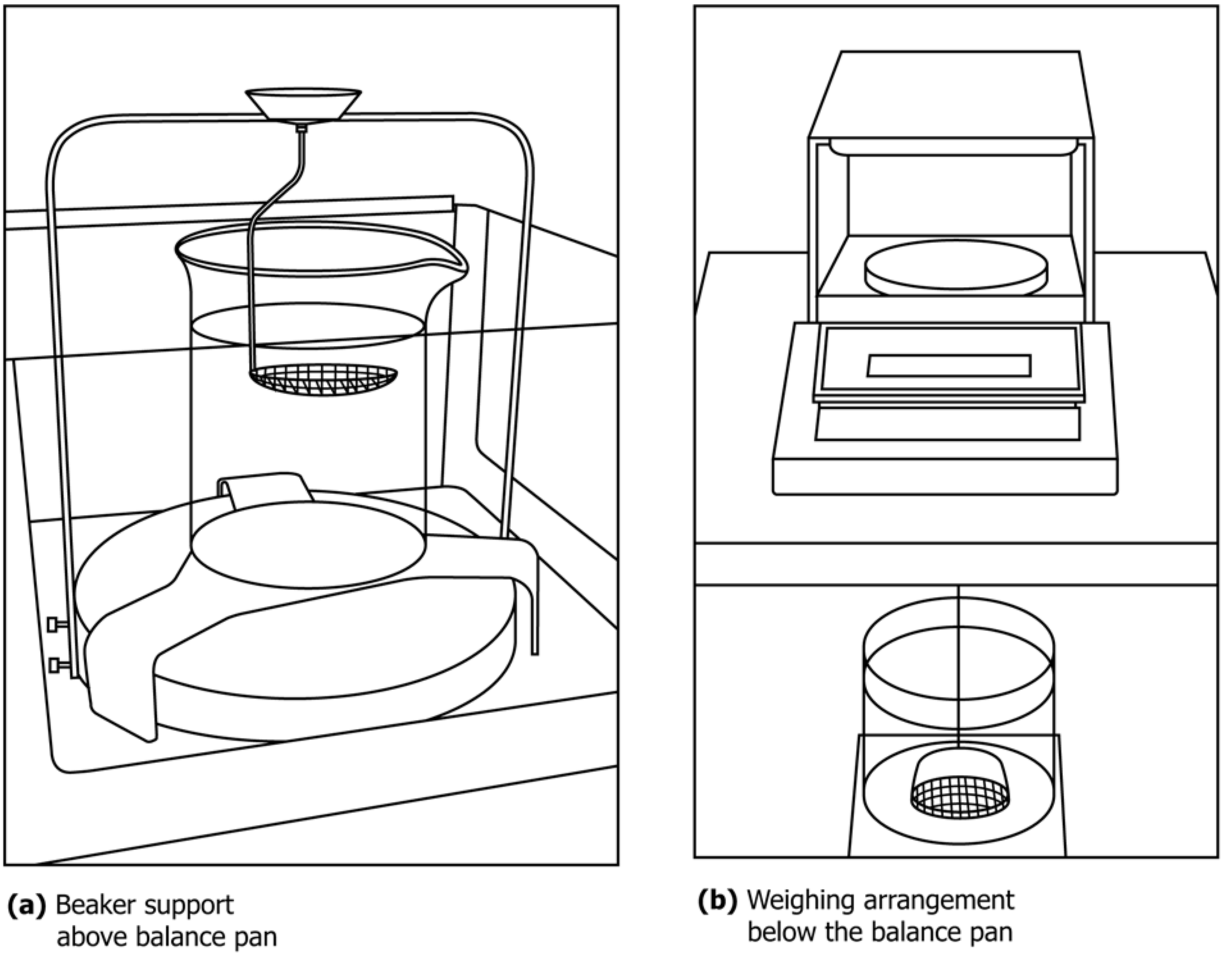

FIG. 2 Methods for Weighing in Water

$$D = (A \times \rho_w)/(A - B + C) = (A \times \rho_w)/(A - F) \quad (3)$$

where:

D = density of test specimen, g/cm^3,
A = mass of test specimen in air, g,
B = mass of test specimen and specimen support immersed in water, g,
C = mass of test specimen support immersed in water, g,
F = mass of test specimen immersed in water with mass of test specimen support tared, g, and
ρ_w = density of water at the test temperature in g/cm^3.

10. Report

10.1 Report the density rounded to the nearest 0.01 g/cm^3.

11. Precision and Bias

11.1 *Interlaboratory Test Program*—An interlaboratory study of the Density Test Method was run in 1990. Eleven test laboratories tested 18 different materials. The design of the study followed Practice E691 and a within-between analysis of the data are given in Research Report RR:B09-1014[3].

11.2 *Test Results*—The precision information presented herein has been calculated for the results from 11 laboratories and for duplicate results for each of 18 materials tested.

11.3 *Precision:*

11.3.1 *95 % Repeatability Limit (within a laboratory)*—The within-laboratory repeatability limit, *r*, as defined by Terminology E456, is estimated to be 0.025 g/cm^3. At the 95 % confidence level, duplicate density test results from the same laboratory should not be considered different unless they differ by more than *r*.

11.3.2 *95 % Reproducibility Limit (between laboratories)*—The between laboratories reproducibility limit, *R*, as defined by Terminology E456, is estimated to be 0.03 g/cm^3 for test specimens with a mass of greater than 5 g. For test specimens with a mass of from 1 to 5 g, it is estimated to be 0.05 g/cm^3. At the 95 % confidence level, duplicate density test results from different laboratories should not be considered different unless they differ by more than *R*.

11.4 *Bias*—No information can be presented on the bias of the procedure in Test Method B311 for measuring Density because no material having an accepted reference value is available.

[3] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:B09-1014. Contact ASTM Customer Service at service@astm.org.

11.5 *Measurement Uncertainty*—The precision of Test Method B311 shall be considered by those performing the test when reporting Density test results.

12. Keywords

12.1 cemented carbides; density; hard metals; metal injection molded (MIM) parts; powder forged (PF) parts; powder metallurgy (PM); powder metallurgy

SUMMARY OF CHANGES

Committee B09 has identified the location of selected changes to this standard since the last issue (B311 – 17) that may impact the use of this standard.

(1) Revised the description of the weighing liquid in 6.2.
(2) Changed the description of the thermometer in 6.5.
(3) Added a note (Note 6) to indicate that several parts may be used to reach the minimum mass level specified.
(4) Re-ordered some of the subsections in Section 8 – Procedure and added some comments about weighing.

ASTM International takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; http://www.copyright.com/